Vol. 19, No. 6 PSYCHOLOGICAL REVIEW PUBLICATIONS June, 1922

Psychological Bulletin

CONTENTS

PUBLISHED MONTHLY BY THE

PSYCHOLOGICAL REVIEW COMPANY
27-29 COLUMBIA STREET, ALBANY, N. Y.
and PRINCETON, N. J.

Agents: G. E. STECHERT & CO., London (2 Star Yard, Carey St., W.C.); Paris (16, rue de Condé)

Application for entry as second-class matter at the post-office at Albany, N. Y., pending

Psychological Review Publications

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ALBANY, N. Y., AND PRINCETON, N. J.

FOREIGN AGENTS: G. E. STECHERT & CO., London (2 Star Yard, Carey St., W.C.) Paris (16, rue de Condé)

Vol. 19, No. 6 June, 1922

THE

PSYCHOLOGICAL BULLETIN

THE PSYCHOLOGY OF TASTE AND SMELL STATUS OF 1922

BY ELEANOR A. McC. GAMBLE
Wellesley College

Since the October of 1915 when Hans Henning published in the *Zeits. f. Psychol.* the first instalment of his work on smell (*Der Geruch*), the psychology of taste and odor has altered almost as much as the map of Europe has changed within the same period. Perhaps, also like conditions in Europe, it has not yet come to a stable equilibrium. To know Henning's work, one might almost say, is to know the psychology of these overlapping fields, for not only is he responsible for the revolution in doctrine, but he has also compiled the most encyclopedic bibliographies which were ever made on these subjects. The student who wishes to orient himself in the psychology, physiology, chemistry, or biology of taste and smell should first read Henning's monograph, *Der Geruch* (1), with its appendix on the taste qualities and its critical survey of earlier work. He should then read Henning's *Physiologie und Psychologie des Geruchs* (2) in the *Ergebnisse der Physiologie* for 1919, and finally his *Physiologie und Psychologie des Geschmacks* (3) in the same *Ergebnisse* for 1921, and should examine the enormous bibliographies to both papers. These bibliographies are supposed to cover the periods from 1902 and 1903, respectively, but, as a matter of fact, they include many earlier investigations. The student, however, who wishes to hunt up the *Ergebnisse* for 1902 and 1903 will find summaries of work on smell and taste by Zwaardemaker, with bibliographies to date. A few investigations covered by these earlier bibliographies are omitted by Henning. The present writer, lacking Henning's enormous library facilities, has not been able to find any

very recent publications of importance to add to the lists of Henning. It therefore seems best to devote the greater part of this report to summarizing the destructive and the constructive work of Henning for the benefit of readers whose interests lie mainly in other fields.

The Qualities of Taste and Smell. In 1915 most of us were teaching our classes that the qualities of smell were an unmapped wilderness as compared with the orderliness of colors and tones. Whereas colors constitute a tridimensional manifold of definitely related terms, smells, we said, are a manifold of indefinitely related terms. Tastes, we believed, were only four in number—apart from fusions. But in 1915 and 1916, Henning gave, or tried to give, us the smell prism and the taste tetrahedron to add to the color pyramid which we now beat into the head of the undergraduate as the canons of the syllogism were beaten into the head of his grandfather.

Let us first consider the question of smell qualities. After the publication of Zwaardemaker's *Physiologie des Geruchs* in 1895, his classification of odors was incorporated, as more or less satisfactory, into most textbooks which dealt with smell in any detail. This classification aims to be a "natural" one, that is, to include in the same groups and subgroups odors which show a mutual resemblance to one another. (See p. 215 of the *Physiologie.*) It is true that the scheme is an adaptation of the classifications of Linnæus and also that for the assignment of smells to classes authority is sought chiefly in the literature of the perfume industry; but it is not true, as Henning alleges (misinterpreting a statement of Zwaardemaker on p. 238) that Zwaardemaker disregarded sensory resemblances. Henning's own classification, however, has a great superiority over Zwaardemaker's in the fact that it is based on the direct experimental examination and comparison of a large number of odors by trained observers. Of this evidence something more will presently be said. Whether or not it is adequate to establishing the complete validity of the smell prism, it effectually overturns Zwaardemaker's scheme, which attempts to arrange, not individual smells, to be sure, but groups and subgroups of odors in a one-dimensional fashion, with fruity odors at one end of the series and fecal odors at the other. Henning, by showing clearly that there are criss-cross transitions between smells of six different types, has demonstrated once for all that *smells, like colors, constitute a tridimensional manifold.* This, in the writer's opinion, is the most noteworthy of Henning's important contributions to the psychology of smell. His prism has become so well known that the writer hesitates to describe it again, yet a

brief reminder to the reader is necessary to give definiteness to this summary. The prism is rooted (1) in the conclusion that smells belong to six main classes and (2) in the view that each of these classes merges more or less directly into every other class through a series of transitional smells. The six classes are the flowery, typified by violet; the fruity, typified by lemon; the spicy, typified by nutmeg; the resinous, typified fairly well by frankincense; the putrid, typified by sulphuretted hydrogen; and the burning, typified by tar. The two triangular faces of the prism are to be made equilateral, whereas the rectangular faces are to be squares. At the six corners of the figure stand, respectively, the most typical smells of the six classes. At the corners of one triangle should stand the typical flowery, fruity, and putrid smells; at those of the other, the typical spicy, resinous, and burning smells. It should be noted that the typical flowery smell is connected with the resinous and the burning, the fruity smell with the spicy and the burning, and the putrid smell with the spicy and the resinous, not by edges of the prism but only by diagonal lines across the square faces. This means that one cannot pass from one member of the pair—say, flowery and resinous—to the other without cutting the series of smells connecting another pair—say, fruity and spicy. At the junction of the diagonals we must, therefore, have smells equally like those at the four corners of the square. These smells Henning believes he has found. The smell of arbor vitae, for example, occupies a central position between the flowery, fruity, spicy and resinous types of odor. Examples of the transitional smells which should stand on the edges of the prism are as follows: Geranium, between flowery and fruity; decaying fruit, between fruity and putrid; the fragrant gums, between spicy and resinous;* vanilla and thyme, between flowery and fruity; the piney smells, between fruity and resinous (camphor, so closely akin to the pines, standing very near the resinous corner); and, finally, the ammoniacal animal odors, between putrid and burning. Odors like garlic are made transitional between spicy and putrid, the mints between fruity and spicy, and the smell of fish-scales between putrid and resinous.

Before discussing the smell prism farther, let us turn to its mate, the taste tetrahedron. Since the earlier work done by von Kiesow

* By an unfortunate slip of the pen, the writer in reviewing *Der Geruch* for the *Amer. J.* (4) reported Henning as placing the fragrant gums, which are obviously somewhat spicy, between resinous and flowery. As a matter of fact, Henning could find no smell transitional between flowery and resinous which did not have either a distinctly fruity or spicy aspect. See p. 298 f.

in the nineties, the orthodox view in regard to the taste qualities has been that they were four in number, and that all tastes other than pure sweet, salt, sour and bitter were mixtures. Henning, however, asserts that the taste of baking soda is no more nor less a blend of salt and sour than the color orange is a blend of red and yellow. This taste has two aspects (*Seiten* or *Aenlichkeiten*), a salty aspect and a sour aspect, just as orange resembles both red and yellow, but one no more tastes true salt and sour at the same time in tasting soda than one sees red and yellow simultaneously when one looks at orange. Thus sugar of lead has also a sweet and a sour aspect, and so on. Just as orange is a unity with an individuality of its own, so the tastes of soda and sugar of lead are unities. To illustrate the interrelations of the tastes, Henning draws his equiangular and equilateral tetrahedron. Its angles are, of course, occupied by the pure and typical sweet, salt, sour and bitter tastes. As already indicated, the taste of bicarbonate of sodium would stand on the line connecting salt and sour, and that of acetate of lead on the line from sweet to sour. The typical alkaline taste would stand between sweet and salt. Between sweet and bitter would stand acetone, between salt and bitter bromide of potassium and chloride of magnesium, and between sour and bitter, sulphate of potassium.

We are now in a position to discuss the prism and the tetrahedron together. These figures resemble the color pyramid in the relation to one another of the qualities which stand at the angles. Like red, yellow or white, the most typical spicy smell—say, nutmeg—and the taste of pure cane sugar are qualities with "only one aspect," whereas each quality in the series which they begin or end has two aspects. As yellow closes the series of orange hues and begins the series of yellow-greens, so nutmeg closes the series in which gum benzoin occurs and begins the series in which vanilla and thyme occur. But the prism and the tetrahedron differ from the pyramid in several important ways. (1) They have an entirely empirical basis, whereas the pyramid is based upon a fact reached only through a high degree of abstraction from crude sensory data but a fact almost self-evident when once discerned, namely, that colors differ among themselves in just three ways, hue, chroma and light-tone or "tint." Thus, it may turn out that there are more than six types of smell, whereas colors cannot well differ from one another in any fourth way. (2) Only the surface of the prism and the tetrahedron are at all comparable to the pyramid; the space within the figures must be abandoned to mixtures of the simple qualities which stand

upon the surface, and if we attempt definitely to locate these mixtures we are geometrically wrecked. (3) The qualities on the edges of the prism and tetrahedron, as Henning strongly emphasizes, are related to one another not like the colors on the edges of the pyramid, but rather like tones in the scale. No simple smell or taste quality, according to Henning (whose view the writer accepts), can be produced by mixing any two others, as—abstracting from the inevitable loss of saturation—we say that we can produce orange by mixing yellow and red. (4) The smells or tastes at the ends of one of the edges differ no more from each other than do the qualities in the middle of adjoining edges. Nutmeg and lemon, for example, differ no more than do vanilla and geranium, whereas red and yellow are more decidedly different than are orange and yellow-green. These last two points bring us to Henning's conclusions with regard to the mixture of smells and tastes, but before we enter upon this topic we should note the evidence for his classification of smells.

Henning made individual experiments upon fourteen adults and five children, and group experiments upon forty-six university students. He also served himself as an observer. Of the fourteen chief subjects (including himself) four were professional psychologists, two more were trained psychologists, and only four had never studied psychology. Two of the professional psychologists had no mean knowledge of chemistry. These were Henning himself and Professor Cornelius, who was especially familiar with odorous substances. Another subject also had studied chemistry and still another had worked in a clinical laboratory. Henning's material consisted of 415 scents of a relatively natural sort—such as essential oils, dried herbs, and the like, of fifty-one artificial perfumes or other trade-articles, and of the uncontrolled smells of daily life, which he caused his subjects systematically to examine. Many of his scents he used in several different concentrations. He made at least some use of six different forms of olfactometer, including Zwaardemaker's, for which he has very little use, but in general he seems to have employed simple scent bottles. His classification experiments were of two sorts. In the first, the subjects were merely required to describe carefully the character of scents presented to them. Their eyes were closed and usually the scents were not identified for them. Upon their descriptions and their confusions of one smell with another, Henning's classification is chiefly based. In the second set of experiments the subjects were given a number of scents and were required to arrange the bottles in series. Of

further details with regard to his method Henning gives exceedingly few. Moreover, he reports only a small part of his results in systematic fashion. His method is rather to make an assertion and then to illustrate it more or less fully from the reports of his observers. But such an elaborate construction as Henning's prism demands elaborate evidence. The present writer is convinced that smells can be ordered only on a three-dimensional scheme, and that a great part of Henning's classification must commend itself to any one who has worked much with scents. The writer is also captivated with the taste tetrahedron. The prism, however, falls short of carrying full conviction.

As regards *method* Henning has made two important points. One is that smelling with one nostril only is unnatural and gives a weak and vague impression of a scent. Hence, the mixture of odors should not be studied chiefly by smelling one with one nostril and one with the other. The other point is the advantage of making the subject describe a scent in ignorance of its nature. The true odor (*Gegebenheitsgeruch*) is localized in the nose and is obtained only by the subject who smells with closed eyes and does not know the nature of the scent. The object-smell (*Gegenstandsgeruch*), on the other hand, is, like color, projected upon the object to which it belongs and is distorted by associative supplementation. The possible distortion of smell experiences by the "residua" of earlier impressions is a point which Henning (5) stresses.

The Mixture of Smells and Tastes. Upon this topic also Henning's teaching is revolutionary. Before his work appeared most of us believed that the phenomena of smell mixture were somewhat parallel to those of color mixture. We believed that if two smells would mix at all, they would make a true blend like the blending of red and yellow into orange. We thought that if two smells would not blend, then the stronger would suppress the weaker; or, if the intensities were equal, we might have either rivalry or else compensation—that is, the suppression of the two smells each by the other. In compensation we believed largely on the authority of Zwaardemaker and Titchener. Some of us had failed consistently in our efforts to get it and von Kiesow and Passy had denied it. But on the authority of the perfume industry at large we believed that many odors could be exactly reproduced by blending other odors. Now Henning's teaching is as follows: (1) The odor of no simple substance (that is, of a substance whose *molecules* are all alike) can be reproduced by blending other odors. It is only by courtesy that

we can, for instance, say that natural and artificial musk have the same odor. But, (2) some smells do make unitary and stable blends or "combination-smells," analogous to orange as a blend of red and yellow. For example, the smell of oil of juniper is a blend, but so unitary is it that Henning allows it to stand on the flowery-fruity-resinous-spicy face of the prism. (3) Other smells either will not blend at all, or will blend only for a moment. Such smells may make loose, chord-like fusions. Subvarieties of these loose fusions are (a) the "coincidence" phenomenon in which by a strain of attention two odors are made to stand out separately, although they possess a certain unity; (b) the "succession" phenomenon in which, one after another, by a shift of attention, each component is made to stand out on the background of the rest; and (c) the "duality" phenomenon in which one of the two odors in a mixture is localized in the right nostril and the other in the left. (4) Some odors will not fuse at all. In this case we may have either rivalry or the suppression of one odor by the other. (5) Odors *never cancel one another*. Henning seems to become enraged every time he discusses compensation, and he is never a diffident critic. Zwaardemaker, he says, made only a few compensation experiments and his own pupils failed to verify his results. He worked with very weak stimuli, so that the phenomenon of liminal fluctuation cannot be ruled out of account. (This phenomenon is more evident with a mixed than with a simple stimulus.) Moreover, a momentary absence of odor could very well be accounted for on the supposition that all the free scent particles in an olfactometer of the Zwaardemaker type are for the moment exhausted. Henning says that he himself experimented on forty-six university students with this olfactometer and did not secure a single instance of compensation. (Here it should be noted that Zwaardemaker replies (6) that Henning did not follow the directions for the proper use of the apparatus.) The phenomenon never occurs in free air, says Henning, and if strong smells could cancel each other, then an apothecary's or a florist's shop or a menagerie would be odorless. The present writer must confess to being one of those persons who never can get a genuine compensation and is therefore strongly inclined to believe with Henning that some apparent instances are to be explained by the fluctuation of attention to a weak stimulus. (5) Smells are more likely to fuse closely, the more alike they are in quality and in feeling-tone, and the more used we are to encountering them together. (6) When smells fuse even loosely the likeness between them is evident

(*eindringlich*) rather than the difference, and even in a true blend we do not get a new smell but one which is like its components.

The phenomena of taste-mixture are almost exactly parallel to those of smell-mixture except that there are more numerous close fusions among tastes than among smells. Among taste mixtures also we find true blends, coincidence, succession, even duality if the stimuli are applied to different lingual areas, as well as rivalry and the suppression of one taste by another. The fusion of a smell with a taste depends upon our localizing them in the same area (as we do in eating) and on our being used to having them together. Thus, salt does not fuse readily with the flavor of wine, nor bitter with the odor of violets.

Taste Contrasts. On this subject Henning is not revolutionary but reaffirms the familiar findings of von Kiesow. He holds, however, that all four of the principal tastes contrast with one another, not excepting bitter (which von Kiesow ceased to except). Henning points out that if contrast is to occur between supra-liminal tastes, mixture must be warded off.

Putting together the facts of mixture and contrast, Henning holds that from the psychophysical point of view taste stands between color vision and smell, whereas smell stands between taste and tonal hearing. The four functions, perhaps, represent four stages in the development of sensory apparatus.

Exhaustion of Smell and Taste. Henning does not deny *Ermüdung* in the case of either smell or taste, but holds that in the former case it has been much exaggerated and much confused, not only with the lapsing of attention but also with narcotic and toxic effects, which he treats in pages well worth reading. It should be noted that *from the standpoint of Henning's views, Aronsohn's physiological method of classifying smells* (*the exhaustion method*) *is not worth an hour's practice.* For not only is genuine exhaustion hard to obtain, but specific energies corresponding to the smell qualities are incredible in view of the primitive structure of the peripheral organ of smell and of the homogeneity of its neurones. The physiological condition of the differentiation of odors and tastes lies, rather, in the different chemical reactions which substances of varying chemical constitution set up in the sensory epithelium.

The Chemistry of Smell and Taste. Henning constructs an elaborate basis in chemistry for his smell prism. He accepts the theory that smell is a constitutive property of the molecule, though he says that this does not prove that chemical elements are odorless.

As regards the "aromatics" of chemistry, he accepts the theory of Zwaardemaker and others that certain groups of atoms, the "osmophors," in the molecule have to do with odor, but points out that substances with different constitution as regards osmophors may smell alike. Three factors, he says, determine odor: (1) the presence of certain osmophors; (2) a kernel or radical for the molecule, to which the osmophors are attached (*an welcher sie sitzen*), which Henning calls the "osmogen" and which may consist of one or more atoms; and (3) the manner in which the omsophors are bound to the radical, that is, the positions they take in the benzol rings. In short, smell in the aromatics is largely a matter of molecular pattern. Henning finds patterns to correspond to each of his six classes of smells, and to the transitions between them. Tastes, also, in the case of organic substances are controlled by groups of atoms, though no one taste depends upon any one group. The group NO_2, for example, is characteristic of bitter substances, NH of sweet, and $COOH$ of sour. With regard to inorganic salts Henning points out that since each has a different taste, quality cannot depend simply on the presence of *anions* or *kations* but must depend upon some relation between the two—perhaps, as Herlitzka suggested, on a difference in solution pressure. Incidentally, it may be said that Henning agrees with Zwaardemaker (7) and disagrees with Teudt in believing that electrical effects have little to do with smell.

Among other matters with regard to taste and smell which Henning treats with full reference to the literature and with illuminating comments are *stimulus thresholds, reaction times, imagery, illusions and hallucinations, feeling-tone, the physiology of the organs, and smell and taste in animals.* His study of smell in ants, which forms the first appendix to his monograph, is a most noteworthy contribution to animal psychology. No space remains for a discussion of these topics here. For a clear, comprehensive and interesting survey of the psychology of taste the reader is recommended to Hollingworth and Poffenberger's little book (8). Unfortunately this book went to press just before Henning's work was known in this country. Whether one agrees with Henning or not, one must admit that any book on taste or smell which fails to reckon with him is somewhat out of date. Since, however, Henning's opinions on taste are not very revolutionary except with regard to the list and relations of simple tastes, Hollingworth and Poffenberger may congratulate

themselves that it was a book on taste and not one on smell that they published in 1917.

Incidentally it should be noted that Hennschen (9), on the basis of a series of examinations of the brains of persons with taste defects, has been led to believe that the cortical centre for taste is not in the horn of Ammon nor in the hippocampal gyrus. He is, however, not very certain even of this negative conclusion.

Finally a word should be said about Zwaardemaker's review of Henning's monograph. Zwaardemaker (6), in view of Henning's scathing and repeated criticisms, has treated the younger writer most magnanimously. He speaks cordially of Henning's psychological work and with appreciation of his wide knowledge of the literature in his field. The almost too marvellous correspondence between Henning's psychology and chemistry of smell, however, is pointed out. This chemistry Zwaardemaker declines for the time being to criticize. His severest criticism amounts to saying that Henning as a psychologist ought not so often to step out of his own field in order to criticize the work of physiologists, to whose technique he is not in a position to do justice.

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THE FLIGHT OF COLORS IN THE AFTER IMAGE OF A BRIGHT LIGHT

BY WILLIAM BERRY
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It is well known that the after image of a very bright light presents the appearance of a series of color changes which persist for a longer or shorter time after the stimulus has been removed. The phenomena have received the name of *Farbiges Abklingen der Nachbilder* (Helmholtz). They have been more or less superficially noted from the time of Aristotle down to the modern period of Physiological Optics. Much of the literature of the subject is in German and French; there being comparatively few original articles in English. Almost all the texts in psychology and physiology refer to the phenomena, usually in most general terms, in the sections devoted to the visual sensations.

The purpose of this report is to review the literature of the subject and to present data drawn from this literature, which in many respects are very conflicting. It may seem to be a rather hopeless task to add anything new to the solution of a problem which interested a Fechner and a Seguin, or bring order out of such conflicting data. A review of the literature, however, suggests, in part at least, the reasons for the disparity between the results obtained. There are several problems which emerge from the review which seem to demand further experimental work.[1]

According to Aubert (6) the first person to make observations on the chromatic *Abklingen der Nachbilder* was Josephus Bonacursius. Aubert's reference is to Kircher's *Ars magna lucis et umbrae,* 1671. In point of fact there are several references to be found in the literature prior to this date. Aristotle reveals a very carefully made observation in the passage in *De Insomniis* (3) which has been translated as follows: "Again, if after having looked at the sun

[1] The writer has carried on a prolonged series of observations with a number of subjects on the flight of colors in the after image of a bright light. The results of these observations will be published later.

or some other bright object, we close the eyes, then, if we watch carefully, it appears in a right line with the direction of vision, at first with its own color, then it changes to crimson, next to purple, until it becomes black and disappears" (4). Following Aristotle almost everyone who wrote on the subject of optics made some sort of generalization on the phenomena and the features of the color transformation in the image. Almost all the observers used the sun as the primary stimulus and then with closed and covered eyes, or closed eyes, or with open eyes observed the shift of colors in the visual field. Plateau (49) has collected the references in the literature upon this and related topics in the field of subjective vision from the time of the Greeks down to the end of the 18th century. In connection with the subject of the color changes in the image, Plateau prefaces his annotated bibliography with some pertinent remarks on the danger to the eyesight in the investigation of the after image of blinding lights such as were used. "The experiments which are the object of this section are dangerous. They are of the sort which have developed in me the germ of an affection which has completely deprived me of vision. I cannot too strongly advise physicists and physiologists to abstain from the same experiments, which present but a slight importance compared with the ills which may arise."

Certainly the rash gazing at the strong light of the sun through a window or even directly in the broad light of day, which seems to have been the method of procedure of all these observers up till quite recent times could not be other than highly imprudent and fraught with evil consequences to the eyes of the unfortunate observer. Helmholtz and Fechner gave specific utterance to a similar warning. Unfortunately in the case of Fechner the warning was not heeded until it was almost too late to prevent unhappy consequences to his eyesight.

As this bibliography of the literature compiled by Plateau is not easily accessible to the average reader, I have availed myself of his work in the preparation of the following summary of the literature from the earliest period. For the most part the references are more or less casual statements without any attempt to elaborate the description or give specific details. This is true of many of the original sources from which Plateau obtained his material. I have, therefore, omitted from this account all but the mere statement of the sort of stimulus which was used in every case and the sequence of colors as it was reported in each case.

Summary of the reports made on the sequence of colors in the after image of a bright light, from the Greek period to the end of the 18th century.

Observer	Stimulus	Sequence of colors in the after image
Aristotle	Sun	Bright, crimson, purple, black.
Themistius	?	Red, purple, alternate, black.
Porta	Sun	Yellow, red, green, blue.
Michaelius	Sun	Bright, red, green, black.
Kircher	Sun	White, yellow, red, green, blue.
Bonacursius[1]	Sun	Yellow, red, purple, several other colors.
Zahn	Sun	White, yellow, red, green, blue.
De la Hire[2]	Sun	Red, yellow, green, blue.
Malebranche	Sun	White, yellow, blue, certain colors made by mixture, black.
Buffon	Sun	No specific sequence given.
Nollet	Sun	White, yellow, red, green, blue or violet, black (frequently the order is irregular).
De Bergen	Sun	Red, orange, yellow, green, blue, violet.
Porterfield	Sun	Red, yellow, green, blue, violet.
Haller	Sun	Yellow, green, blue, violet.
Aepinus[3]	Sun	
Scherffer	Candle flame	Natural color, with a black border, changes to bright red, green, then a mixture of green and dark blue, then the image appears black.
	White cloud	Dark blue, green, reddish orange, purple.
	White paper in sun's rays	Dark blue, green, orange, purple.
Mongez	Sun	Red, orange, yellow, green, blue, indigo, violet.
De Godart	White paper in the sunlight	Pale yellow, golden yellow, yellowish green, green, violet, blue, purple, reddish brown.
Venturi	Sun, candle flame, white paper in sun	White, yellow, red, indigo, blue, green.

[1] Plateau briefly notes the observations of Bonacursius in his review. As the volume of Kircher's *Ars magna lucis et umbrae* could not be found by the writer, the following account has been taken from Aubert (5): "Among other observations Josephus Bonacursius mentions this . . . In any place which is closed as completely as possible so that no light whatever may enter, leave an opening covered with paper on which you draw any figure, or preferably, silhouettes of things. Also let the opening be facing the sun so that it may be illuminated by the sun. Having arranged this, fix the eyes on the paper opening and gaze steadily for a considerable time till the retina of the eye has taken in the image completely. Then, having closed the window fix the eyes on a white paper, and lo, wonder to relate on the paper you will see as it were the rising dawn, yellow being generated first, then red, next purple and lastly all the colors of the rainbow and finally

During the following century there was extraordinary interest in the problems of subjective vision, and many investigations were carried on by physicists and physiologists. Laymen also contributed to the general fund of information, as is evidenced by the numerous articles to be found in the reports of learned societies, etc.

At the beginning of the century Thomas Young (70) delivered his *Lectures on Natural Philosophy*. He mentions the fact that the impression of light on the retina is in some degree permanent, but he is not sure whether the retina possesses this property merely as a sort of solar phosphorus, or by virtue of some peculiar organization. If an object is painfully bright it generally produces a "permanent" spot which continues to pass through various colors for some time without much regularity and then vanishes. "This may, however, be considered as a morbid effect."

R. W. Darwin (15), writing on "Ocular Spectra," remarks: "On looking for a time on the setting sun so as not greatly to fatigue the eyes, a yellow spectrum is seen when the eyes are closed and covered, which continues for some time and then alternately disappears and reappears." This yellow becomes blue when the eyes are opened.

Goethe (23) describes in some detail the color changes in the image derived from a piece of white paper held in strong sunlight.

after a long time, you will see the figure of the opening in inverted colors which at length degenerates into a beautiful azure color mixed with intense red."

[2] De la Hire's account of the phenomena is involved with the description of the effect of the mixture of the image with other colored objects. "Mais si l'on regarde des objets differemment colores, les taches paroissent de differentes couleurs par la comparison de celles qui les environment et par leur mélange avec celles, ce que l'on peut connoitre facilement" (18).

[3] It appears that Aepinus (1) alternately opened and closed his eyes during the period of the after image. After fixating the sun for 15 secs. he observed the image as follows. These details are taken from Brewster (9). After fixating the sun and shutting the eye he perceived an irregular pale yellow image of the sun, greenish and surrounded by a faint red border. As soon as he opened his eyes and turned them towards a white ground, the image was brownish red and the border was sky blue. When he again opened his eyes the image of the sun became green and the border became red. On a white ground the image was redder than formerly and the border was a brighter blue. On closing the eyes again the image appeared green, approaching to sky-blue, and the border was red. With a white ground again the image was red and the border was blue, but the shades of these colors were different from the previous ones. At the end of four or five minutes, when the eye was shut the image was a fine sky-blue and the border a brilliant red. These changed, when the eyes were opened, to an image of brilliant red and a border of fine sky-blue. Aepinus observed that the image frequently disappeared and reappeared, and that it generally disappeared when he wished to examine it and reappeared when he was not prepared to observe it.

If one regards an object, colorless but dazzling, it makes a strong impression which is lasting, and the *Abklingen* is accompanied by color phenomena. After stimulating the retina by a piece of white paper and turning the eyes towards the darkest part of the room, he saw a "round image" which was colorless but bright in the middle, then somewhat yellowish with a purple edge. This lasted for some time until the purple encroached from the border and presently covered the whole image. Immediately the edge began to turn into blue and this in turn passed gradually inwards to the center, meanwhile the edge became dark and uncolored. Again the center changed by the involution of the edge, so that the entire image became dark and colorless. The image declined in size and intensity. Goethe observed the length of time the image persisted. He fixated for five seconds, then closed the shutter (the paper was illuminated by sunlight passing through a small hole in the window shutter) and found that after thirteen seconds the image was completely purple, after a period of twenty-nine seconds more it was blue, and after forty-eight seconds it appeared colorless. Opening and closing the eyes prolonged the image to about seven minutes.

Purkinje (53) obtained the flight of colors by gazing at the flame of a candle for some time. With eyes closed and covered with the hands, he noted a bright after image, which quickly disappeared and was followed by a bright red. This disappeared, leaving a dark space in the center, surrounded by a weak gray. This became brighter and contracted towards the middle, leaving a darker edge. The bright center faded and finally vanished, leaving only a grayish haze over the whole field. With a longer period of fixation he found the same sort of transformation but with a longer period of duration of the image. He generalizes on the result of his observations that on the average the time relations are in the proportion of one second of fixation to twenty seconds of duration (image).

Brewster (10) records the results of his own observations in connection with his discussion of the work of Aepinus. He modified the procedure of Aepinus in some respects. Having selected a very bright summer day he obtained by means of the concave speculum of a reflecting telescope a very brilliant image of the sun on the ground. He "tied up" his right eye and gazed with the left eye intently through a tube at the solar image. "When the retina was highly excited, I turned the left eye towards a white ground and alternately opening and closing the eye observed the following spectra."

Spectra with the eye open	Spectra with the eye closed
Pink surrounded by green	Green
Orange mixed with pink	Blue
Yellowish brown	Bluish pink
Yellow	
Pure red	Sky blue
Orange	Indigo

To Fechner (20) belongs the distinction of having made the first extensive series of observations on the color changes in the images of very bright lights. He remarks that the investigation of the *Abklingen der Farben* has been carried on hitherto in a rather superficial manner and for the most part with the dazzling images (*Blendungsbilder*) given by the sun or a flame. His own observations were extended over some time and frequently repeated. He calls attention to the possibility of individual differences in the details of the phenomena and the necessity of the coöperation of a number of observers.

For the production of after images Fechner used the following stimuli: (*a*) White clouds viewed through a circular opening in a dark room, the size of the opening being about 4.4 cm. in diameter; (*b*) white paper on black paper viewed in the direct sunlight; (*c*) white paper on a black ground illuminated by the sunlight focused on the white paper by means of a lens; (*d*) the sun, viewed directly, with a slightly cloudy, or very bright blue sky.

The duration of the exposure was a half to one minute long, and the images were observed with closed eyes covered with the hand. All the stimuli gave approximately the same results, with very minor differences, stimulus *d* and then stimulus *c* being most effective in the production of the most beautiful and enduring stages in the image. Fechner gave a very detailed analysis of the phases of the after image. The sequence of colors is, white (only with stimulus *d* and perhaps *c*), light blue, light green, dark red, dark blue. The first stages of the sequence pass more rapidly than the later. The phases are characterized by the color quality of the central part of the image, although there are other areas in the image which are distinguishable on account of difference of coloration. On account of the exceedingly fugitive character of the color transformations in the image, it was necessary to make very many observations on the separate areas of the image. He distinguishes

four such areas, '*Central*,' *Saum, Umring, Randschein*. These are, an inner disk; a border about the central disk not sharply separated from it; a more centrifugal border, rather sharply separated from the inner border by color differences and broader than the former; and farther out a more or less extended field of color or perhaps mere brightness. In general, the colors involute from the periphery to the center. A color will begin to develop in the periphery and pass toward the inner disk, finally overcoming it and occupying the whole of the central part. Meanwhile a new color may have begun to develop on the border in order to pass through the same course. Thus a succession of colors is being developed at the periphery, frequently the latest one is at the border before the preceding color has reached the center. The more intense the primary light; the more slowly do the sequence phases pass away. With a lesser degree of intensity of stimulating light the transformation from the light blue to the dark red is apt to be through bright reddish yellow rather than through green. The duration of the primary fixation does not seem to have an appreciable effect on the colors of the image.

In another place (20b) Fechner laid down the general rule that whenever the duration and the intensity of the stimulus has reached a certain degree, any increase either in intensity or of duration does not alter the constancy of the phenomena. The series is, white, blue green, red, and frequently blue. The stimulus was a white object on a black ground. During the first three phases the image is brighter than the *Grund des Auges*, but with red it becomes darker. There thus enters a stage where the complementary gains the superiority over the primary. Further, in the same article Fechner reports that the image of a piece of white paper upon a black ground in direct sunlight, viewed for a very brief time, showed blue, green (red-yellow) red, and again blue or blue-green. If the duration lasted merely for a "moment" the image was at first bright blue, violet, dull yellow or yellow-green; a series of colors never perceived after a longer duration.

Knochenhauer (34), following Fechner, became interested in the character of the after images of various kinds of light with open and closed eyes. Unfortunately it is almost impossible to find out from his account much information concerning these images. He used a variety of stimuli, *e.g.*, strips of white paper in broad daylight, the sun viewed directly or through clouds, reflected sunlight from mirrors, gold leaf in sunlight, etc. He had two main conditions, the image with eyes open and eyes shut. He made a distinction

between two kinds of after images. The first class is that where the images in both open, closed and covered eyes are complementary to the perceived object, and a second class where the images in both open and closed eyes are complementary to one another. The first class are called *Subjective Nachbilder,* and the second class are called *Blendungsbilder.* This distinction is valueless on the basis of the data he has given.

Müller (43) described the colored spectra from the impression of colorless objects. "If the eye, after viewing the sun, be exposed to perfect darkness, that is, if light be entirely excluded from it, the colors of the spectrum will succeed each other in the inverse order, namely, from white through the lightest, and then the darker colors, to black; thus, in the order of white, yellow, orange, red, violet, blue, and black." "These phenomena, which cannot be explained by any external conditions acting on the eye, are another proof that colors have their immediate cause in the conditions of the retina itself."

Brücke (11) asserted that the after image of the usual mixed light (white), when the light intensity is only moderately strong, is colorless, but with light of a greater intensity the image may be of a lively coloration. Thus, after looking at the sun, he had a bright green or bright blue image surrounded by a bright red or orange. Again, after looking on a white field directly illuminated by strong sunlight he obtained a green image which became blue, then violet, and finally deep red. All the colors were brighter than the ground. After the red had disappeared no new color came; the field remained black, darker than the background. According to Brücke a positive image is one in which the brightness relations in the after image are the same as they are in the object. Conversely, a negative image is one where the brightness relations are reversed. The positive image shows features which are not present in the negative. The color changes which have been called the *Abklingen der Farben* appear in his experience only with positive after images, but they do not appear with all positive after images. The color transformations are most clearly seen with stimulating lights which are most like white light. His explanation of this fact is as follows: "I suppose, therefore, that it is attributable to nothing other than that the positive images of the lights compounded together in the white light temporarily fall apart."

Seguin's contribution to the experimental literature is notable for his thoroughgoing and careful analysis of the details of the stages in the chromatic series. His reports, extending from 1851 to 1880,

are the result of very many observations carefully made and minutely recorded. He states that the after image of a white object is always colored, whether the illumination is strong or weak, and when the duration of fixation is for one or two seconds or up to the point of dazzling (60). Nevertheless, the character of the image changes with the brightness of the stimulus and the length of time of exposure. In general, the colors in the image are disposed in a central area and, around this, in the form of concentric zones. The progression of the colors is from the periphery to the center. (Le centre de l'image passe donc successivement par toutes les teintes qui s'étaient montrées d'abord plus ou moins distinctement à la périphérie.)

Seguin's analysis of the chromatic changes in the after image provides for two series which differ according to the nature of the "tints," their behavior, and the circumstances of their production. Thus, after viewing a very bright surface, the colors appear very brilliant and clear in the closed eyes. The succession is very rapid from green through blue to violet. This is the first series. Then the other colors appear, darker and moving with less rapidity from the circumference to the center of the image. This is the second series, which nevertheless is not complete in the case of a very short exposure. If the duration is prolonged over about twenty seconds, after the dazzling of the first few seconds, one is able to recognize the colors of the first series, either complete or reduced perhaps to two or even one color only. Then the image assumes a definite form and the colors appear very distinctly. The second series in this case reaches full development and includes yellow, orange, red, violet, blue and green. Seguin adds that when the duration of exposure is very short the series may comprise yellow and green only, or yellow, red and green, or again yellow, red, blue and green, thus approaching completion more or less, according to circumstances.

Whenever the brightness of the stimulus is of low degree the image presents the colors but in fewer number. The series then is blue and violet, then nuances of yellow or red, and finally green.

According to Seguin the first series and second series appear to conflict at the point in the image when the first gives place to the second. This is indicated by mixtures of the blue or violet of the first series with the yellow of the second. (Il y a une sorte de trouble dans la partie centrale de l'image des nuances indécises et mélangées, par exemple un mélange de bleu, de violet et de jaune; souvent une teinte blanchâtre, provenant peut-être de la superposition de ces dernières couleurs.)

In the case of a very powerful light such as that of the sun received in the full light of day, the colors of the image are very numerous. In addition to the positive series, including white, yellow, green, blue and violet, one is able to distinguish in the negative image two groups; one where the colors are "washed with white" and very transitory, the other less bright, although brilliant and persistent. The complete negative series includes, therefore, blue, green, yellow, orange, red, violet, blue, green, yellow, with a reddish zone (63).

Seguin describes the positive series of colors as follows: It includes yellow, green, blue and violet, and these colors are very fugitive, especially when the duration of contemplation (exposure) has been prolonged. They are "accentuated" when the stimulus is very intense. These, he adds, are the characters of the positive image of a colored object; we are thus led to regard the first series as the positive image of a white object. (Ces caracteres sont ceux de l'image positive d'un objet coloré: nous sommes ainsi conduit à considérer la première série comme l'image positive d'un objet blanc.)

Scoresby (57) reported to the Royal Society the results of an inquiry concerning optical spectra in respect to color in the images derived from the influence of light. Objects under low illumination do not ordinarily give chromatic images. Ordinary daylight and bright sunlight especially give spectra with remarkably vivid hues. It is asserted that some modifying factors of the chromatic spectra are differences in the intensity of the external light, the duration of the exposure and the condition of the retina at the time of exposure. Unfortunately there are very few data given to explain and support these generalizations. A low degree of daylight seems to have given an image with a dingy orange color, which became olive, yellow gray or bluish black and lasting only for a minute or less. Medium degrees of daylight produced an image with crimson pink, purple pink, violet, purple, indigo, blue. Still higher degrees of daylight gave different results, which were "far more uniform than those from inferior light." The series here was: Green, yellow-green, yellow, orange, red, scarlet, crimson and brown, or olive. "This series, it is observable, is particularly accordant in respect to the principal or fundamental colors with that of the prismatic spectrum from green to yellow, orange and red." Experiments (not described) showed that the photochromatic developments have some relation to the time of fixation, and the intensity of the light. "Thus the higher colors of the spectral series elicited by strong light

could, within certain limits, be also developed by more continuous gazing with inferior light: so that the pink colored spectrum derived from ten to twenty seconds gazing in low degrees of light could be elicited by a single glance under bright sunshine." A general proposition is stated to the effect "that we shall not be far wrong, perhaps, in considering the intensity of impression as the product of the time of gazing into the relative quantity of light admitted by the aperture."

Helmholtz (26) substantially agreed with Fechner and Seguin with regard to many of the details of the flight of colors. The series varies according to the duration and intensity of the primary impression. After a brief exposure the first white is very transitory and passes through greenish blue into a beautiful indigo blue and later into violet or "rosy" red. Then follows a dirty grayish orange, which marks the shift of the positive image into a negative image, and in the negative image the dirty orange frequently becomes a dirty yellow-green. With very short exposure of the primary light, the orange phase frequently marks the end of the image, which disappears before becoming negative. If one permits light to enter the eyes during the course of the flight of colors the general effect is to throw the image over towards the later stages of the flight, and the removal of the secondary light results then in a return of the image to the earlier stage. Thus, when the image is blue in 'absolute' darkness, if light is allowed to enter the eyes, the image shifts through reddish into a negative yellow image. If the eyes are covered quickly the image returns to blue. After a longer exposure and a more intense stimulus the image on a dark ground shows the following colors: White, blue, green, red, blue, and on a white ground, finally blue-green and yellow. The image becomes negative at the red phase. Helmholtz seems to find a difference in the behavior of the colors according as the image is of a moderately illuminated surface or of a dazzling object such as the sun. With the former images he noticed that color changes take place either over the whole surface or advance from this or that side in an irregular order. On the contrary, the color changes in the image of a dazzling object, *e.g.*, the sun, usually take place in a regular order, from the periphery towards the center (die Farbenänderungen des Bildes vom Rande nach der Mitte hin vorschreiten).

Fick (21) quoted the sequence of colors according to Helmholtz and gave an explanation of the phenomena in terms of Young's theory, and the "fatigue" hypothesis.

Aubert (5) refers to the images we are considering as *Blendungsbilder,* on account of the effect of the primary stimulus on the eye, which hinders the perception of objects of weak illumination. In this respect his use of the term is different from that of Knochenhauer. The *Blendungsbilder* arise only in the cases where the primary stimulus is very intense, as in the case of the sun or of a very bright flame. He points out that they have been obtained from lights of various kinds under different conditions of dark adaptation and with different degrees of brightness in the backgrounds. The number of variations in the image is extraordinarily large and it is impossible to obtain all the phenomena in a single observation. Aubert confirms Fechner's results as to the sequence of colors, with this exception, that between the light green and the negative red of Fechner's series Aubert found a yellow with a bluish edge, and after the negative red there is a positive yellow, which becomes white surrounded by a red field, which in turn is succeeded by an extraordinarily beautiful blue. The series of colors for Aubert is, therefore, as follows: White, light blue, light green, yellow, red, yellow, white, blue.

The same alternation between positive and negative images was noticed by Aubert, which had already been noticed by Fechner and Brücke. Aubert, however, asserts that with him the change from positive to negative was more frequent than was the case with Fechner. Aubert gives some details of the image in peripheral vision, which had barely been mentioned by Purkinje. The after image of the sun or a candle, obtained by looking at the light with rapid jerky movements of the eyes to one side, shows about twenty or thirty degrees from the center as a bright area (*glanzende Nachbild*); beyond that nothing at all appears. In his experiments with the electric spark Aubert was unable to find color in the after images, nor did he find color when the spark was seen peripherally through colored glasses.

Rollett (54) investigating the problem of subjective contrast in the after image, used colored glasses and also a white glass placed in the opening of a window shutter. He placed the glass so that it was surrounded by a dull, almost opaque, contrast surface. All experiments were made on very bright days between the hours of 9 A.M. and 2 P.M. He obtained dark adaptation by holding the hand before the eyes, and the exposure was made by rapidly withdrawing the hand and replacing it. The duration of the exposure was roughly timed by counting three from the beginning of the movement of the

hand away from the eyes to the return of the hand. The sequence of colors with the white transparent glass was greenish blue, violet (somewhat purplish), violet red, very pale pink, dull yellow, olive green. The phenomena were not essentially different when a "dull" white glass was used.

Hering did not pay much attention to the colored images of a bright light stimulus, evidently regarding them as insignificant. In the *Lehre vom Lichtsinne* (27) he mentioned the fact of their existence under certain conditions, where the color of the image and the *Lichthof* vary accordingly to the character of the light used, whether natural or artificial. Later on in the same work he remarked that the *Blendungsbilder* with the darkened eyes reveal the most beautiful saturated colors (27b). (Die dann im verdunkelten Augen erscheinenden Blendungsbilden zeigen bisweilen so gesättige schöne Farben, wie kaum das Sonnenspectrum). In his reply to v. Kries's criticism of his theory, Hering briefly notes v. Kries's remark, "that it is very difficult to understand how, according to Hering's theory, a colored *Abklingen* after stimulation with white light could take place" (35), and asserts that "most white lights are not 'neutrally white,' but have their color 'valency,' which is not apparent in ordinary vision. White light may be much mixed with color before it becomes perceptibly colored. Ordinary daylight has been shown to have color valency by Brücke and also by Hering" (28).

Harris (25) reported vivid after images of white paper illuminated by sunlight, the colors being rose pink followed by canary yellow. His explanation of the phenomena is in terms of Hering's theory.

Hodges (31) reports a number of observations which he made with the sun shining through a clear glass window and also through a slightly whitened window. With twenty seconds' fixation the image was colored a brilliant yellow green, dull orange, pink, rich crimson, dull purple and then blue. In a subsequent article (30) Hodges states the results of his observations in a series of propositions. Among other things he concluded that—

1. The color of the after image of a bright light is not in any way dependent on the color of the object, but upon the amount of light thrown on the retina, either by the amount in the light itself or by the amount of time during which one looks at it.

2. The succession of colors in the forming and waning of the image follows the order of the colors of the spectrum. Using white paper with ten seconds' exposure in sunlight he obtained with closed

and covered eyes an image in which the first color was blue, with fifteen seconds' exposure he obtained green, with twenty seconds yellow-green, and with twenty-five or thirty seconds the image was a vivid yellow-green or pure yellow. Increasing the duration of the exposure did not produce further changes. The order of disappearance seems to have been constant for Hodges and was always orange, crimson, violet, blue.

Cattell and Farrand (13) had seventy-five students tested for ability to see after images. Among other facts, the authors report the disappearance and reappearance of the images (oscillations). Cattell (14) described a remarkable case of prolonged duration of an after image. He "obtained (after resting the eyes five minutes and exposing them for one minute) an after image of the clear sky and the bars of a window, which can be seen at the present writing, after an interval of eight months. During the first hour the oscillations occurred continually, at first at intervals of about ten seconds, the panes and bars displaying brilliant and beautiful colors, mostly greens and purples. In the course of the first month the after image became gradually less distinct. On closing the eyes it always appeared positive, becoming negative after a few seconds, and passing through a series of oscillations which could be continued indefinitely by altering the illumination. Since that time the after image has become continually less distinct."

Washburn (67) made a very interesting contribution to the discussion of the subject in her report on the effect of sustained attention on the normal flight of colors, with the effort to "alter the colors subjectively." In order to determine the "effect" or "change" it was necessary to establish beforehand the normal flight of colors for a few subjects. These were three in number, in addition to the author, who first established the "normal sequence." The stimulus was reflected light from the sky. The three subjects, all students of psychology, were practised "until there was consistency between the reports." This appeared to be necessary, as the writer points out that "a wholly unpractised observer watching the course of an after image for the first time reports chaotic results, and no two such observers agree as to the alterations in color which occur." The results of the practice "were almost perfectly uniform." The *exact* sequence of the colors is rather hard to determine from her account. After the momentary positive same-colored image there was an interval followed by a positive image. This was colored with patches of red or green. Then the image revealed the "panes" as sky blue.

This passed into vivid green, which usually disappeared and reappeared five or six times, growing paler, almost whitish, towards the end. This neutralizing of the green seemed to be due to the gradual emergence of the complementary color, for the next color was red. This in turn gave place to a deep blue image, which lasted longer than any of the others, growing gradually darker until it became indistinguishable. One subject characterized the last phase as dark green or sometimes as bluish green. The duration of the exposure in this case was twenty seconds, with the light from an upper part of a window. With variations in the time of exposure to ten and fifteen seconds the course of the image was not affected. Variations in the intensity of illumination used did somewhat influence the color changes. With a cloudy sky and much diminished illumination the blue and green positive images were missing.

In another article (68) Miss Washburn reported a number of observations on the color sequence in the after image in central vision and in peripheral vision. Her method was that of "overlapping images in such a way that the portion of the retina which corresponds to the overlapping part of the image shall have been stimulated twice as long as the portions corresponding to the rest of the image." This, it was suggested, would provide a method of studying the effect of duration of the stimulus superior to that of a comparison between successive stimulations. The stimulus in the first experiment was transmitted sunlight through a window from a cloudy sky or from a "sun illumined snow field." The sequence of colors under these conditions was, after a short after image of the window, bluish white, changing to a rather bright blue, green, red, dark blue, very dark green sometimes indistinguishable as to specific color. The duration in this case was fifteen seconds, and is designated as the maximum duration. As the intensity was the maximum obtainable for ordinary daylight, this sequence of colors is called the "maximum color series." No change was observed when the duration was increased. No statement is made as to the periods of duration which were used. When the field of stimulating light was uneven in its stimulating effect the image showed disparate color sequences. "The more stimulated parts of the image (as to intensity) take longer to go through the succession of colors than the less stimulated parts."

Thus the parallelism appears to be somewhat like this, the more stimulated parts of the image lagging behind the less stimulated parts by approximately a "stage" in the color sequence.

More intensely stimulated parts	Less stimulated parts
Blue Green, etc.	Green Red, etc.

"Thus we can see that after the maximum series has been reached, increase in the intensity of the stimulating light increases the duration of the several color stages in the series." The author does not indicate the position of these parts in the image and the reader is left to wonder whether she is speaking of the central image and the surrounding color regions such as have been described before as *ring* and *edge* and outer *field*, or of something else. She "overlapped" the images from successive stimulations of the retina, so as to obtain a zone of coinciding images and disparate zones, one on each side. This was done by "fixating one point on a bright surface for about fifteen seconds, closing the eyes for an instant and then fixating a different point on the stimulating surface for fifteen seconds." According to the author the overlapped part of the image corresponds to a part of the retina which has been stimulated during a period twice as long as the other parts. The result is that the overlapped part of the image exhibits the same sort of behavior as did the image produced by more intense stimulation. The schema appears to be like this:

Single image	Overlapped images	Single image
Green Red, etc.	Blue Green, etc.	Green Red, etc.

In other words, "when the maximal series has been reached, further increase in the duration of the stimulus increases the duration of the color stages in the series." If the intensity be reduced or the duration shortened to seven or eight seconds, the sequence of colors is different. The series is blue, red, darker blue, faint greenish black. Thus the chief difference is "that the first green stage is dropped out." This is stated to be the "first qualitative effect of diminishing the intensity or duration of the stimulus." Approximately the same sort of change takes place with further reductions in intensity or time of exposure. Formally stated, the result is as follows: The progressive effect of diminishing intensity or duration, is a shortening of the stages of the maximal series, dropping out of

the first green stage; shortening the stages of the second series (blue, red, blue, green), dropping out of the second blue stage.

Miss Washburn also reports some experiments made with peripheral vision. The stimulus was white daylight through a square opening in a black window screen, subtending an angle on the retina of about 1.5 degrees. The peripheral distances selected were between five and fifteen degrees. No data are given beyond a few general observations. The most noteworthy of these are: The peripheral image is smaller than the central image; the positive white-light image is practically colorless in a darkened field with covered eye; the negative image comes after a long interval and is difficult to see. "But when it comes it is always colored, a violet red, often scarcely distinguishable from the dark field, but unmistakable in color when seen."

Külpe (37) noted the sequence of the flight of colors in the after image of the sun. "Thus, after looking at the sun for at most 0.5 seconds I have seen (1) a bright after image, which (2) took on a red border; (3) then the center became green, and a violet area appeared beyond the red border; (4) then the violet became dark gray and the red and green center pure blue; (5) then the blue changed to white, with a red border; (6) then came a rose-violet center, with dark blue border, while the dark gray area beyond took on a greenish color; and finally (7), the whole image was blue, with bright green border, upon a white field. This succession of phases occupied several minutes, and others would undoubtedly have followed if I had not interrupted the observation."

Franz (22), writing on after images, called attention to the fact that individuals differ in their account of the color changes, and further, that the same individual did not always see the same colored after image when stimulated with the same light. "At one time, all the images would be seen as light alone; at another, they appeared gray or reddish. This change appeared with all my subjects."

McDougall (39) has written on the *Farbiges Abklingen* of after images in some detail. His observations were made on the images from white light from various sources, which range through different degrees of intensity. All lights, "except in the case of the dullest light that will yield an after image in the dark," show coloration in the after image. It is by no means easy to disentangle the facts from the account given by McDougall. Apparently he used different durations, as well as different intensities, but they seem to have been used in an irregular order. The results of his observations may be conveniently summarized in the following tabular form:

	Stimulus	Description of the image	Sequence
	Dim white light	A fuzzy gray patch, which dies away in the course of a few seconds.	
I	Dull white light	Sometimes hazy for one or two seconds, sometimes a gray, and sometimes a blue follow immediately. Red appears almost invariably a few seconds after light is excluded. Struggle with green. Green predominates and persists to end.	Gray or Blue Red Green
II	Rather brighter white light	Colors more saturated. Blue, though frequent is least constant, and is often replaced by violet tinge. Red is rather less constant, the last green is always dark, and of fair saturation.	Blue or Violet Red Green
III	Still brighter white light. Reflected sunlight through milk glass. (Fixated spot on disc, with both eyes at 18 inches distance. Duration of fixation varied.)	*Case A.* Fixation for ½ second. Bright blue image of fair sat. Then less sat. and gives way to dark green. *Case B.* Fixation for 5 seconds. Hazy at first, then bright red came out of haze. Red disk became momentarily yellow. Gave place after 30 sec. to dark pure green. Faded slowly. *Case C.* Fixation for 20 seconds. Bright yellow-green disk with red edge. Red disk with patches of y-g. Pure red disk, with narrow blue border. Red shrinks and disk becomes blue, with patches of red struggling in center. Blue wins and remains for about 50 seconds. Green then fills the image and fades slowly.	Blue Green Hazy Red Yellow Green Yellow-Green Red Blue Green
IV	Still brighter white light. Transmitted sunlight through ground glass. (Fixation for 25 seconds.)	Brilliant bluish-white, became blue-green, with green edge. Blue disappeared leaving bright pure green disk. Red appeared on the edge, green retreated and y-g patches appeared on red disk. Then disk became red with blue edge. Red and blue struggled as before, leaving a blue disk. This persisted for some time, struggled with green, and green persisted to the end.	Blue-White Blue-Green Green Red Blue Green

McDougall adds: "The two observations last described illustrate a very constant feature of such after images, namely, the tendency of the three primary colors to follow one another in a recurring cycle of the order G.R.B.G.R.B. In one case the cycle passes from G. to G., in the other from B. through G.R.B. to G. again, thus almost completing the double cycle." It must be noted, however, that the stimuli were not the same, nor were the periods of exposure equal. Further, the sequence is not from G. to G. except in one case, that with twenty-five seconds' exposure. In the other observation the first green is described as 'bright' yellow-green. On the basis of the evidence given it is difficult to accept the statement of the cyclical character of the sequence. The author supplements the above account by some further statements. He says: "An important feature of the after images of bright white light is that, after the first short period in which the two colors fuse to give yellow, or, as in the case after the brightest lights, all three fuse to give white, the colors that in turn occupy the area of the after image alone and unchanging for considerable periods, are R.G. and B. only, and these are in every case of exactly the same color-tone, although varying in brightness or intensity in different cases and in different stages of one after image." "The yellow which frequently follows at once upon the white light always reveals its mixed character by resolving itself into green struggling upon a red ground, or, more rarely, into red struggling upon a green ground."

Nagel (44), who was a deuteranope, points out that in his own case the stimulation of the retina by a strong white light produces a very lively blue image. Projected on a small bright color field, the blue of the image supplements the yellow to form white. Nagel tried the effect of a very short period of stimulation of the retina and obtained a blue after image. He exposed one eye to the bright light of the sky for 0.1 seconds. There was a colorless interval of several seconds, then the image developed as a well-saturated dark blue, upon which the after image of the darker objects, *e.g.,* the window bars, stood out in dark yellow. He remarks that under the same conditions in which he sees the image as a lively blue other observers with normal color sense see the image as colorless. Priestley (52) quoted M. Hey to the effect that a person who recovered from complete amaurosis reported that the first time he saw the fire it was a bluish color. This observation, says Priestley, agrees with that of De la Hire and others that the weakest impression produced by objects very luminous is bluish. Edridge-Green (19) reported

a case of red-green color-blindness (male) where the image of the sun thrown on a white wall was seen as a black spot. "This spot does not appear colored or change color, but simply fades away."

Scott (58), investigating the general problem of suggestion, conceived the method of "controlling by suggestion the sequence of colors in the visual after image secured from fixating white light." College students were used. These were doing "the first course in experimental psychology at the time." The method of procedure was to take the subject into a room filled with colored objects, color charts, color wheels, etc. A prism was used to produce a spectrum. "The student was told that just as the prism analyzed the white light into the spectral colors so an after image from white light would contain the spectral colors in sequence." The entire situation was intended to increase the suggestibility of the subject. The stimulus was light which came through a 12 cm. square opening in a screen. At a distance of three meters the subject looked through the opening directly into the white skylight. The duration was twenty seconds; then with closed and covered eyes the subject began to report the sequence of colors perceived. Leading questions were given to enhance the suggestive value of the experiment. "Let me know as soon as the red appears." "Is it red yet?" etc. This was continued for twenty seconds or until red was reported. The same procedure was continued for the other spectral colors. Some images lasted for several minutes, but sometimes the duration was as short as thirty seconds "succeeding the first appearance of any color." Only those records were used where there were "colors reported for the twenty seconds succeeding the first report of the presence of any color in the after image."

According to Scott the sequence under these conditions is "first a blue, then green, then red and then finally a blue." Red does not ordinarily appear during the first twenty seconds. If it did appear in this experiment it was due to "suggestion." "Apart from suggestion an orange would certainly not succeed a red during the first twenty seconds." Scott gives very few data in connection with this part of the experiment. Under "suggestion" one subject gave these reports for three trials:

(1) Red, orange, yellow, green, blue and violet.
(2) Red, orange, yellow, green.
(3) Red, orange, yellow, green, blue and violet.

In later trials the conditions were changed somewhat, the subject being told that "with the new conditions the spectral order would

not be secured." The subject then reported in three trials "the normal sequence, with certain variations as is common to this experiment." In one trial red appeared before it should have done, *i.e.*, "before the limit of twenty seconds." Orange did not succeed a red.

Titchener (65) remarks of the observation of the flight of colors in the after image that "it shows in a striking way the effects of practice. The report of a wholly unpractised observer is a mere chaos. With attention, the uniformity of the phenomena soon becomes apparent; and presently the observers, who at first gave radically different accounts of the after image, will reach agreement upon all essential points." His report of the sequence is somewhat detailed. "With an unclouded sky, or a sky thinly covered with clouds and presenting an even white surface," the flight of colors is as follows: (*a*) A momentary positive and same colored image; (*b*) interval of five or six seconds; (*c*) positive image, with patches of red and green; after one or two seconds the image becomes sky blue; (*d*) green takes place of blue; green suffers some saturation changes, becomes paler, almost whitish. Some observers now see: (*e*) Yellow, regularly followed by (*f*) deep red; the image here becomes negative; red fluctuates; (*g*) deep blue; persists for some time and gradually darkens with or without passing into (*h*) a dark green image. The sequence therefore is blue, green, yellow, red, blue, green.

Homouth (32) has made a very detailed study of the color sequence in the after image; this being in every way the most extensive treatment of the subject which has appeared in recent years. Homouth used chromatic light stimuli as well as white light, and the major part of his data is devoted to the experiments with the colored stimuli. His source of light was a Nernst lamp of about 330 candle power placed in a dark box. The aperture was keystone in shape, with the dimensions of 15.4 cm. radius and 10 degrees angular distance. The light rays passed through a milk glass plate placed in the front wall of the box, and the intensity of the light was cut down by a sheet of writing paper. He used a dark adaptation period of ten to twenty minutes before each observation, with a period of exposure from one to four minutes long. The author seems to have been the only observer, the series of observations extending over a long period of time. Several factors are mentioned as conditioning the results, chief of these being a long continued period of practice in the observation of the after images. Dark weather and good health seem to have been favorable conditions for the experimental

work. Of the light stimuli used, a yellow light produced an image in which the chief features of the flight of colors were observed to the greatest advantage. Spectral analysis showed this light to be relatively very composite. The white light used is described as presenting an appearance of a weak yellowish toned white. The chromatic after images of this white light are stated to be in many instances completely identical with those of the yellow light. Homouth described at length the color changes of the yellow light, and his account of the changes in the white light image is stated in terms of differences between the two series. (Mit dem durch die Gelberregung hervorgerufen psychischen Erfolge ist er in einigen Fällen vollständig identisch. Die Unterschiede sind folgende.) He distinguishes four regions or areas in the image, to which he applies the names, (*Kern*) center, (*Rand*) a narrow border, (*Kontrast Rahmen*) outer edge and (*Hof*) the field out to the extreme periphery. Homouth has presented some excellent colored sketches of these areas in the after image (32b). The sequence of changes in the different areas is shown in the following table.

The numerals refer to the stages of the image:

Kern	Rand	Rahmen	Hof
1 Deep indigo blue well saturated.	Slightly sat. purple - violet.	Pure white.	Greenish. Some violet in the extreme periphery (very indistinct reddish violet).
The reddish violet of the extreme periphery appears to spread over these regions.			Greenish.
2 Blue.	Yellow present indicated by brown spots in the purple-violet.		
3 Blue shows in spots through purple - violet (From the Rand).	Yellowish.	Yellowish.	Greenish.
4 Yellow begins to cover the center. Rivalry and some brownish mixtures.		Yellowish to brownish orange.	
5 Center becomes more brownish, yellow tending to predominate.			
6 More sat. yellow.	Areal distinctions have almost disappeared.		

This series shows a sequence of three colors, blue, purple-violet, and yellow. "These colors are not connected with each other in steady transitions but always shift abruptly. During almost the whole period of the flight these three colors strive together for supremacy. Particular stages of this rivalry are those *Schlierbilder* in which at the same place of the visual field two of the three colors appear to consciousness." He points out what other writers have noted, that the colors under certain conditions move from the periphery towards the center. (Ein Zurickspringen der Farben vom

Centrum nach Peripherie habe ich jedoch hier nicht beobachten können).

Other experiments were made with sunlight in direct vision and also " morning light " through a milk glass plate. The image of the sun, after direct fixation for about 0.5 minutes showed on a dark field these changes: A small image of bluish white color, surrounded by greenish yellow, and this in turn surrounded by a purple red border. Then the greenish yellow overflowed the blue, which, however, reappeared through the yellow. This was followed by the overflow of the purple red over the whole image. Eventually the yellow reappeared in the center, and out of the yellow came light blue. This process was repeated several times. Then appeared on the border dark blue, which spread over the entire image, and out of the blue reappeared the purple, then yellow, and lastly light blue. (Eine Farben von der anderen noch eingefasst oder sie vollständig verdrängend, wobei wohl auch ein oder das andere Bildchen einmal ausblieben kann). The series ended with black, which appeared as an indefinite shape surrounded by dirty yellow. The duration of this type of after image was estimated to be five minutes or more.

The sequence of colors in the after image of " morning light " seen through a milk glass was greenish yellow, surrounded by purple red and a reddish field. Then followed a well-saturated yellow, surrounded by purple and a bluish gray field. The purple then filled the center, which was followed by well-saturated blue, pale greenish blue, reddish yellow, in which blue would appear as a tiny spot.

Homouth states the chief results of his experiment as follows: (1) The colors of the after image are not connected with each other through gradual transitions, but appear somewhat sharply separated from each other in the visual field. (2) The qualities in these discrete stages of the Abklingen are, for all the stimuli, approximately, the same three, and these are blue, purple, and yellow.

Miles (41) devoted a section of his article on the " Formation of Projected Visual Images " to a brief discussion of the color changes in the image. The subjects were asked to report the appearance of the " fixated cross " in the image and the color of the disc upon which the cross appeared. He used as stimulus the light from an incandescent mantle exposed for two seconds. All work was carried out with bright adapted eye. He reported that his " records emphasize the fact that, in visual experiences, individual differences are most marked." Color changes for some subjects were " very scanty," and " in these cases the image was of short duration." For others, there

was considerable play of very vivid and distinct colors. "This seems to show that a regular color sequence for light of any particular physical intensity is dependent on personal characteristics, and is not a resultant of the absolute intensity of the light." One subject gave reports of a regular sequence, blue, green, red. Another gave blue, red, "with yellow appearing as frequently as green." Other subjects "show but little evidence of any predominating sequence of color." In connection with the duration of the image, he noted that some subjects "appeared to show very little variation in the duration of the image from test to test." Others began with long duration images and steadily decreased, as the observations were continued. A third type "showed the reverse effect." In one case "no image was seen after the first two exposures. Then followed, at successive tests, images which lasted 47, 125, and 168 seconds, respectively."

Stevenson (**64**) performed some experiments at the University of Cincinnati on the negative flight of colors from a white light. He used a strong Nernst lamp as a stimulus. "The observer looked into the dark box from which all light had been excluded. At a signal, the experimenter raised the shutter, allowing the subject to look directly at the stimulus for different periods, from one fourth of a second to thirty seconds, and then the shutter was dropped." "When an image was seen in the dark box, the shutter was raised and the image projected on the white screen. Thus, for each image recorded in the dark box, one on the white screen was recorded." His summary of results in part is as follows: (1) The order of colors and the duration of the flight depend upon the intensity and the duration of the stimulus. (2) The negative flight can only be observed when alternated with the positive and soon fades away when projected upon a white surface. (3) The negative lasts longer than the positive. (4) The positive colors can be seen in a dark box when the eye is in full light of a room, but the flight does not last as long, nor is it as definite as when the eye is in complete darkness. (5) The first reports of most subjects are definite for the middle phases.

The essential features of this review of the literature from the beginning of the nineteenth century to the present time may be conveniently shown in tabular form. The following tabular summary shows the type of stimulus used, together with the details of the color sequence in the image:

Summary of the reports made on the sequence of colors in the after image of a bright light, from the beginning of the 19th century to the present.

Observer	Stimulus	Sequence of colors in the after image
Goethe	White paper in bright sunlight.	Brightness, yellowish, purple, blue, dark.
Purkinje	Candle flame.	Brightness, bright red, dark, followed by a brighter center. Becomes gray.
Brewster[1]	Reflected sunlight from mirror.	Spectra with the eye open Pink, orange, yellowish brown, yellow, red, orange. Spectra with the eye closed Green, blue, bluish pink, blue, indigo.
Fechner	Sun viewed directly.	White, light blue, light green, dark red, dark blue.
	White paper illuminated by sunlight.	Bright blue, violet, dark yellow or yellowish-green.
Brücke	Reflected sunlight from white field.	Green, blue, violet, deep red.
Seguin	Bright surface.	Series I Green, blue, violet. Series II Yellow, orange, red, violet, blue, green.
	Sun directly viewed.	Positive series White, yellow, green, blue, violet. Negative series Blue, green, yellow, orange, red, violet, blue, green, yellow.
Scoresby	Sunlight through window.	Green, yellow-green, yellow, orange, red, scarlet, crimson and brown, or olive.
Helmholtz	White light	White, greenish blue, indigo blue, violet or rose-red, grayish orange, dirty yellow-green.
	(Longer duration and more intense light).	White, blue, green, red, blue (on dark ground) and (on white ground) finally blue-green and yellow.
Aubert	White light	White, light blue, light green, yellow, red, yellow, white, blue.
Rollett	Sunlight through window.	Greenish blue, purplish violet, violet red, pale pink, dull yellow, olive green.
Hodges	Sunlight through window.	Yellow-green, dull orange, pink, crimson, dull purple, blue.
Külpe	Sun	Center of Image Bright, green, pure blue, white, rose violet, blue.
Washburn[2]	Sunlight through window.	"Maximum" series Bluish white, bright blue, green, red, dark blue, very dark green.

Observer	Stimulus	Sequence of colors in the after image
McDougall	Sunlight of different degrees of intensity.	(I) Gray or blue, red, green. (II) Blue or violet, red, green. (III) Yellow-green, red, blue, green. (IV) Blue-white, blue-green, green, red, blue, green.
Scott[3]	Sunlight.	Blue, green, red, blue.
Titchener	Unclouded sky or thinly clouded sky.	Positive and same colored, interval, positive with red and green, after a short time becomes blue, green, yellow, deep red, deep blue, dark green.
Homouth	Nernst lamp.	Blue, reddish violet, blue, yellow, and some "brownish mixtures," more saturated yellow.

[1] According to Brewster the eyes were alternately opened and closed during the experiments. It has frequently been pointed out that the effects of a secondary light upon the image is to cause it to shift towards the later stages of the color transformation. Further the vision was monocular during fixation. The effect of monocular vision on the color changes has not been carefully investigated up to the present time.

[2] This is the series which Miss Washburn designates as the "Maximum series" derived from the maximum duration and the maximum intensity of light stimulus (sunlight).

[3] Scott apparently took this to be the normal flight of colors on the authority of some previous writers.

SUMMARY OF LITERATURE

In the course of development of the literature on this subject the following results among others have been obtained:

1. The flight of colors has been obtained from different types of light stimuli. These are in part listed by Aubert as follows: The sun (Newton, Fechner); a bright flame (Purkinje); sunlight on white paper (Fechner); concentrated sunlight on white paper (Fechner); sunlight on white paper viewed through dark tube (Brewster); sunlight through window of dark room (Bonacursius, Fechner, etc.); electric spark (Seguin, Aubert). In addition to these, there have been the later observers who have used sunlight either reflected or transmitted. Homouth used a Nernst lamp.

2. The sequence of the colors in the after image has varied from one observer to another. Only in one or two cases has there been close agreement.

3. Several observers agree that the colored after image varies with intensity and duration of the stimulating light. Fechner,

Helmholtz, and Washburn agree that the phenomena are constant after a certain duration and intensity are reached, but below these the images vary in content and duration.

4. Goethe, Fechner, Seguin, Helmholtz, and Homouth agree that under certain circumstances the colors of the image involute from the periphery towards the center. Homouth and Seguin assert that the colors in the image of a very bright light do not always pass from periphery to center, but may appear in the center. Helmholtz asserts that the colors in the image when the stimulus is a moderate illumination appear to be irregular in the manner of their appearance.

5. Brücke and Scoresby assert that objects under low illumination do not give colored after images. On the other hand, Seguin asserts that the image of a white object is always colored. Very few experiments with low illumination have been reported.

6. The doctrine of the cyclical character of the color transformation in the after image has been advanced by McDougall. The cycle is a recurrent one of three colors, green, red, and blue. McDougall is not supported by the other observers in this opinion.

7. Washburn and Titchener have asserted the uniformity of the phenomena for the practised observers. Helmholtz also remarked: "There appears to be no essential difference among different persons in respect to the course of the after images of intense lights which have been developed under the same conditions. So far as they go my observations agree with those of Fechner and Seguin." On the other hand, Fechner, Seguin, and Plateau recognized the variability of the phenomena for different observers, at the same time insisting on the necessity of investigation of the invariable as well as the variable elements.

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CUTANEOUS SPACE

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The literature on cutaneous space during the past two years comprises a few studies of local signature, an experiment with a temperature esthesiometer, two cutaneous studies with amputates, an investigation of after-images of movement, considerable discussion of illusions especially those of motion and an experiment on the dynamogenic effects of light. Some foreign literature of earlier date which was delayed by the war is included in the present review.

Ruediger (9) discusses theories of tactual local signature especially the "sensory complex" theory versus the "sensory element" theory. His own experiments appear to substantiate the latter. The subject with eyes closed was touched upon the radial forearm, and then localized the spot with eyes open. Pressures of ten grams and one gram were used. According to the "sensory complex" theory the stronger stimulus should give more accurate localization. It failed to do so and in fact there was a slight tendency in the reverse direction. Moreover with the stimulus applied over a vein, where the subcutaneous portion of the complex would be uniform, less accurate localization should be found than elsewhere on the arm. The opposite result was obtained with seven of the eight subjects. In a supplementary series pure cold sensations were obtained and these were located as accurately as touch sensations or touch and cold combined. The writer therefore inclines to the "sensory element" theory.

Lufkin (7) disputes Watt's proposed "attribute of order" which, among other things, is based on the fact that "every touch spot can be distinguished from every other." Watt's experiments were performed on the forearm and Lufkin tried a region on the back where localization would be as free as possible from "empiristic motives (images, reflexes)." Preliminary experiments located an area bounded by the scapulae and the seventh and tenth cervical vertebrae where the observer was often unable to tell whether the right or left side of the spine was stimulated. Selected pressure spots in this region were systematically studied. Successive stimulation of two

spots on opposite sides of the spine yielded thirteen per cent. "same" judgments. There were also some judgments of this sort when the two spots were on the same side. The percentage of such judgments varied inversely with the distance between the points. With the same spot stimulated twice the report "same" was given only about half the time. The results do not confirm those of Watt on the forearm and the conclusion is that localization is a matter of perception rather than of sensation.

Turro (11) gives a critical resumé of theories of tactual space. As a result of his own experiments with children he concludes that in order to localize one needs either active movement or the reproduction of ideas of movement. In a study of amputates he found correct localization only when the subject moved the stump.

Katz (3) studied over one hundred cases of one-arm amputation. The usual illusion of the missing member was diminished in size in nearly every case. This is ascribed to loss of peripheral excitation. Normally we have a sort of sensory "tension" built up through experience out of our tactual and kinesthetic sensations from the limb, and the absence of these sensations gives the illusion that the limb is smaller. Experiments upon the side of the stump and a corresponding area of the normal arm yielded lower thresholds for touch and two-point discrimination on the stump. Articles placed on the stump were recognized more readily than on the normal arm. Localization, however, was poorer on the stump with a constant error in the direction of the shoulder. The author considers these phenomena to be due to attention.

Piéron (8) reports a novel study of thermal-spatial discrimination. The esthesiometer deposited two drops of water on the skin, thus giving a thermal stimulus without a pressure stimulus. Two-point thresholds were determined in this manner while the temperature of the water was varied from 32 degrees below skin temperature to 21 degrees above. At about skin temperature the threshold was much higher than at extremes of temperature. Comparison with an ordinary esthesiometer on the same cutaneous area was equivocal because of the difference in the size of the stimuli. It is obvious from the experiment, however, that there is a thermal-spatial discrimination.

Thalman (10) applied a moving stimulus to the forearm to see if an after-image of movement would ensue. Various stimuli were used—a knotted string, a wide strip of muslin, a belt of corduroy and a belt of corrugated muslin (with transverse strips attached

at intervals). The speed of motion and time of application were varied. All four stimuli produced some instances of negative after-images of movement. Only the corrugated muslin, however, gave compulsory conditions. With this stimulus (applied longitudinally) it was possible to find a speed and time for each subject at which he reported the after-image on every trial. The stimulus was sometimes removed when the motion stopped and was sometimes allowed to lie stationary against the skin. The latter condition was more favorable to the after-effect. Similar results were obtained on the calf of the leg with one subject. An additional series was performed under compulsory conditions to obtain detailed descriptions of the after-effect. It sometimes appeared cutaneous, sometimes subcutaneous, and sometimes both. In the first case it had a "bright" quality and in the second a "dull."

Benussi's discovery of a tactual illusion of movement produced by the stimulation of separate points in quick succession has been previously corroborated. Recent studies make a more careful introspective study of the illusion. Whitchurch (13) stimulated marked pressure spots using two intensities of stimulus, one that involved only the cutaneous organs and the other both the cutaneous and the subcutaneous. Optimal conditions for the illusion were determined. The distance and the time-interval between the stimuli were the most important factors in conditioning the optimal movement. The illusion involved an integration of quality, time, and cutaneous extent—a pressure diffusing, growing, and extending in time. Andrews' (1) preliminary series was similar to the above but two of his three subjects reported no movement at all. Hence he repeated the stimulation of a pair of spots several times in succession, *i.e.,* gave a rapid alternation of the stimuli for from 5 to 15 alterations. This procedure was designed to strengthen the association between the two spots. The instructions included "process" as well as "meaning." In this experiment all the subjects reported the illusion. It was variously described as a movement of one member, of both, or as full movement from the first point to the second. The "bow" movement in the air above the skin first described by Benussi was sometimes obtained, especially with one subject. Objective conditions did not seem sufficient for this illusion, the idea of the movement was necessary. In the "bow" movement when the subject attended to the sensations the "bow" disappeared leaving only the discrete pressure. The processes that carried the meaning were visual, kinesthetic, or both.

Krass describes a number of illusions involving every-day material. A variation of Aristotle's illusion is obtained (6) by rotating the left hand 180 degrees and placing it palm upwards on the table, while the right hand is placed palm downwards upon the left. A key laid along the inner side of both thumbs and moved by the middle finger of the right hand is then felt as two keys joined at the end. With the hands in the same position and the key placed across the hand with the ring on the left thumb and rotated by the forefingers of both hands the apparent rotation is the reverse of the actual. If the flat end of a pencil (4) is pressed on the ball of the finger so that it does not leave its position and the other end of the pencil is moved about, it seems as if the flat end were larger and made of gum. If a glass (5) is held with one hand while the other strokes the rim, the glass seems larger tactually than it does visually. If the inside of the glass is stroked with the ball of the finger it seems smaller.

Johnson's (2) subjects sorted cards that were perforated with four patterns of four holes each. Large goggles with frosted glass were worn so that, as the subject faced a wall he saw a uniform brightness but could, of course, discriminate nothing. In other series the subject wore the same goggles but the room was in darkness. Results were reduced to indicate the percentage of superiority of the performance in card-sorting under the light conditions over the performance under the dark conditions. The results of six subjects showed differences in favor of the light that are significant from the standpoint of probable error, with seven subjects there were slight differences of the same sort, while two others showed a slight, one (an astronomer) a large, difference in favor of the dark condition. The distribution curve of all the differences appears somewhat normal but the mean of the differences is plus 2.09 per cent., *i.e.*, in favor of the light conditions. Johnson concludes that "the inference seems justified that the tactile sensitivity is enhanced by uniform stimulation of the retina by light even though the visual and tactual impressions cannot be referred to the same object and vision cannot serve as a means of orientation."

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SPECIAL REVIEWS

J. W. Bridges. *Outline of Abnormal Psychology.* (2d Ed.). Columbus, O.: R. G. Adams, 1921. Pp. 226.

The second edition of Bridges' book comes at a time when popular as well as scientific interest in abnormal psychology has undergone considerable quickening because of the large number of mentally abnormal cases due to war, both soldiers in the army and others in civil life. In the present edition some errors have been corrected, and new material has been added. Blank pages are left for "notes." The second part, "The Mental Syndromes or Symptom-Complexes in Insanity," and the third part, "The Borderline Diseases: Psychoneuroses and Epilepsies," are retained although they are not properly subsumed under the title *Abnormal Psychology.* These two parts outline the groupings of symptoms, and in some instances the course, the etiology, and the nature of the disease.

Some of the defects of the first edition have been eliminated, references are more frequently given with dates so that editions of books can be determined, typographical errors have been partly corrected, and some definitions have been changed. In a first edition of a work of this character, involving as it does considerable checking and reference, much may be overlooked and criticism of minor points withheld. In a second edition it may reasonably be expected that all gross errors will have been checked, and that some of the lesser ones will be dealt with. In the present work, and the reviewer will confine himself to the part dealing with abnormal psychology, these expectations have not been entirely met.

The effort is made to give the neurological correlates of the abnormalities, which effort leads to absurdities of speculation. This is not decried as a totally bad practice, were it not for the fact that frequently the statements are given in such positive language that the reader is permitted no alternative unless his reading go beyond the limits of the references. The author goes so far as to state that any other explanation "does not relieve one from the necessity of giving an explanation in neurological terms" (p. 31). Synaptic resistances are overworked as explanatory conditions. In one place (p. 82) the changes in synaptic resistance is said to result in "a systematized amnesia."

Among matters needing revision or explanation are the following: the second definition of abnormal (p. 9) is a definition of pathological; pathopsychology and psychopathology are not necessarily parts of abnormal psychology (p. 10), they may be its correlates; decreased function (hypo- conditions) are not classified with the absences, increases or perversions (p. 10) but are in a separate group; reference to neurological literature will show that lesion of the primary cortical stations in the post-central convolutions is not accompanied by loss of cutaneous and kinesthetic sensations (p. 24), but by losses of special sensory abilities; the refusal to accept a distinction drawn by Esquirol is not a "theory" (p. 26); logorrhea cannot be a verbal hallucination described as "the escape of thought" (p. 28) and at the same time (p. 97) an "extreme garrulity"; there would appear to be no reason in a psychological text for an appeal to teleology (p. 43); in speaking of paradoxia sexualis it is meaningless to say that one form is a "*premature* development . . . *beyond the age of the child*" (p. 38); it is pedagogically bad, to say the least, to separate two conditions which are conceded to be alike without defining the supposed differences, as in speaking of "lower motor neurone" paralyses "and peripheral paralyses" (p. 89); the use of the description "at rest" (p. 91) does not define the conditions in an individual who is trying to maintain his balance on one foot; the invocation of the concept of memory loss to account for functional paralyses (p. 92) and for the aphasias (p. 95) is very questionable and probably gratuitous in view of the recent publications on the latter subject.

It is advantageous to get the facts clearly presented, and to indicate the possible or probable directions of explanation, but no good purpose is subserved by including meaningless and ill-formed statements. The criticisms are offered as additions and corrections; if space were available more points would be dealt with in the hope that the next edition will far surpass the second.

Shepherd Ivory Franz

Government Hospital for the Insane

Henry H. Goddard. *Psychology of the Normal and Subnormal.* New York: Dodd, Mead, 1919. Pp. xxiv + 349.

The hypothetical flow of a postulated neurokyme over an imaginary neuron pattern is the keynote of explanation in Goddard's recent book, *The Psychology of the Normal and Subnormal.* The

book is written for "those beginning the study of psychology in Normal Schools and Colleges, teachers who read for themselves, parents who desire to understand their children." It will be interesting and profitable reading for all these people, but that it can serve as an introduction to general psychology is not probable, because it is not systematic, does not cover the whole field of general psychology, is practically silent on the elementary processes, has too much space given to inconsistent hypotheses, and shows practically no knowledge of recent experimentation in general psychology. One of the most frequent references is to James whose psychology was elaborated 32 years ago. There are 55 references, about half are psychological, practically none to original sources in the periodical literature of psychology.

The book begins with a discussion of the nervous system. The plates are good and the descriptions clear. But why should there be such a chapter in a psychology? Until we can *know* what nervous processes underlie conscious processes, and can formulate the laws governing these neural processes, nerve physiology can be of no service to psychology. It is the business of psychology to discover and formulate the laws and principles involved in the relations of stimuli to responses. For practical purposes these relationships are all we need to know. A college student having difficulty with his lesson will get no help from figure 18. A father looking for guidance in training his wayward son will get no assistance from figure 11.

In Chapter II Goddard discusses reflexes, instincts, perceptions and ideas. The discussion is in terms of neuron patterns. The reflexes and instincts depend upon inherited patterns. The author seems to accept the idea that consciousness is due to resistance in the synapse. "May it be," he says, "that two nerve fibers in contact or in close juxtaposition make manifest the energy otherwise imperceptible?" (p. 27). "The consciousness resulting from two or even twenty neurons is too faint to be consciousness, but when thousands are involved, it rises above the threshold" (p. 28). "Consciousness, especially in the higher thought processes is in some unknown way the result of some interference with the free flow of neurokyme" (p. 28). Neural interference gives rise to consciousness, the greater the interference, the greater the consciousness. When we come to Goddard's discussion of attention, we find that height of attention depends upon *ease of flow* of the neurokyme (p. 77). These two theories are inconsistent. In explaining the

conflict of stimuli in attention, we find (p. 79) the following: "There is a ready formed, instinctive pattern to which the stimulus of a loud noise instantly leads, arousing strong activity with its accompanying consciousness. But what becomes of the consciousness existent when the loud noise interrupted us? The answer is, it is eclipsed by the greater consciousness aroused by the stimulus." Thus, astronomy is brought to the aid of psychology! It has been a tradition in psychology now for some time to say that consciousness is due to interference in the flow of neural energy, when the least reflection or experimentation shows that the richest consciousness is in connection with *inherited* neural activity, in which case the flow must be easy and uninterrupted. In a violent emotion, so strongly do the processes involved hold the center or focus of consciousness, that other stimuli for the time can not be effective in arousing focal consciousness.

In chapters 4, 5, 6, 9, and 10, Goddard treats of memory, imagination, association, attention, and other higher processes. In his treatment of memory, in the main he follows Titchener. His explanation of the feeling of familiarity (p. 71) can hardly be satisfactory to the critical reader. We find the useless distinction between association by contiguity and similarity. On page 95, Goddard identifies them, but on pages 99 and 101 we find them to be different again. The author does not seem to see that identity of experience is the basis of all association.

On page 121, we find all important mental processes reduced to unity. "There is no possibility of differentiating (imagination, memory, association, attention) because they are all one and the same thing . . . only different phases of the same mental process" (p. 121). One might as well say that because a ball is both red and round, redness and roundness are one and the same thing, both being characteristics of the same ball.

In chapters nine and ten, thought and reasoning are discussed. "Thought appears when neurokyme in a simple neuron pattern is interrupted under conditions where there are associated neuron patterns into which that neuron energy may flow and lead to action" (p. 164). It is difficult to see in what sense "thought" is used. If *consciousness* is meant, the quoted statement can hardly be true. In the summary, p. 173, we read, "perception, judgment and reasoning are all phases of the thought process." Can it be that perception is due to interference? And can it be that "sensation is the consciousness of a stimulus"? (p. 165).

The psychology of learning is disposed of in a 14-page chapter on habit which shows no knowledge of the recent experimentation in this important field.

In his treatment of emotion, Goddard takes a position essentially the same as that of James. A situation sets into action various glands and other internal organs, by means of the sympathetic system. This activity sends to the cortex a complex stimulation which occasions sensations which are the essential part of feeling and emotion. We are not told whether feeling is another kind of sensation, whether it is a conscious element correlate with sensation, or whether it is an attribute of sensation.

One of the most interesting discussions of Part II concerns mental levels and their determination. In this field the author is at home and speaks from his large experience. The reader here finds helpful treatment of moral training, the relation of intelligence to control of the emotions, the moral imbecile, and various pedagogical applications of the facts discussed.

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Downey, J. E. *Graphology and the Psychology of Handwriting.* Baltimore: Warwick & York, 1919. Pp. 142.

Dr. Downey has here summarized in compact form the present state of theory and experiment in the field of graphology and the psychology of handwriting. The material is presented in two sections. The first deals with three topics: (1) the basal concepts of graphology; (2) graphological methods, and (3) the graphological elements. The second section discusses some of the author's own experimental work on (1) the analysis of the factors entering into disguised handwriting, (2) the influence of mental and physical condition on handwriting, (3) the comparison of handwriting with other forms of motor expression, and (4) the comparison of graphological with character traits. Several of these studies are here presented for the first time. In the last named study the author discovered several very significant relationships, especially between small writing and interest in detail ($r = +.61$).

The main purpose of the book, as expressed by the author, "is one of orientation, preliminary to an attempt to use graphic activity in tests of temperamental or character traits." On the whole it serves its purpose well, though the person familiar with the tests

since developed by the author will find some difficulty in paralleling the test series with the material presented in this book. As a resumé of progress in the psychology of handwriting this volume stands alone.

M. Freyd

Ossip-Lourié. *La Graphomanie.* Paris: Alcan, 1920. Pp. 232.

This treatise on the disease of writing too much opens with a short review of the origins of written language and the underlying psychology of language. Under pathological conditions written expression degenerates. The object of the author is not to study such derangement but to observe literary graphomania as it occurs outside asylums. He does not, however, succeed in drawing a clear-cut picture of the malady. Mania for a literary career may be a common attribute of many sorts of egocentric vain individuals. Nor does the author draw a line between second and third-rate writing and the morbid variety. Possibly he thinks no line should be drawn. The creative writer who writes in order to say something instead of writing in order to write is not concerned with reputation. The graphomaniac suffers from the delusion of grandeur and wishes to draw attention to himself. He has a remarkable verbal memory and goes from the word to the idea; his pen moves faster than his attention, hence stereotypy and echo-phrases are a feature of his work.

Although literary graphomania is the chief form, there are other varieties of the disease, such as the mania for carving one's name on public monuments or on natural wonders (glaciers are cited!), and the mania for writing letters of the everyday and the anonymous sort. There are also simulators whose mythical productions never see the light of print. All in all, a frightful epidemic has invaded the world. Few individuals are immune, the majority have written or are writing a book or a pamphlet. Letters by the milliard, books by the thousands, pamphlets innumerable! And in train of the graphomaniac trails his sad satellite, the reading-maniac, vainly striving to keep abreast of the flood.

In discussing the causes of graphomania, the author blames, in part, a system of education which encourages writing without thought, by utilizing copy and dictation. The man who really thinks never writes rapidly; but rapid composition is enforced in school routine. Graphomania flourishes because of the failure of true criticism and the commercialization of literature. And then there

is the woman-movement,—and all women writers with only a few exceptions are graphomaniacs!

As a curative measure the author suggests educational reform. Graphomaniacs, once afflicted, rarely recover, but isolation, solitude, and silence are recommended as therapeutic measures worth trying.

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NOTES AND NEWS

A MONUMENT to the memory of the late Professor G. T. Ladd of Yale University, whose death occurred at New Haven on August 8, 1921, was unveiled in the grounds of a Buddhist temple near Tokyo, Japan, on March 11. The monument consists of a slab of grey volcanic rock. It stands on the top of the hill of the bell tower in the grounds of Soji-ji, the great Buddhist temple at Tsurumi. Beneath the slab are a part of the ashes of the psychologist and philosopher, brought to Japan at his request.

THE sixteen hundred volume library of the late Professor G. T. Ladd of Yale University, has been given to the Hatch Library of Western Reserve University from which Professor Ladd graduated in 1864.

PROMOTIONS in psychology and educational psychology at Columbia University are announced as follows: At Barnard College, Dr. H. L. Hollingworth to a full professorship; at Columbia University, Dr. A. T. Poffenberger to an associate professorship; at Teachers College, Dr. A. I. Gates, Dr. W. A. McCall and Dr. L. S. Hollingworth to associate professorships.

DR. HERBERT S. LANGFELD and DR. EDWIN G. BORING have been appointed associate professors of psychology at Harvard University, and Dr. Carroll C. Pratt instructor in psychology at Harvard University. Dr. Langfeld is promoted from an assistant professorship at Harvard. Dr. Boring has been professor of experimental psychology since 1919 and Dr. Pratt instructor in experimental psychology since 1921, both at Clark University. The psychological staff at Harvard will consist of Professors McDougall and Dearborn, Associate Professors Langfeld and Boring, Dr. Troland, and Dr. Pratt. Professor Sanford remains at Clark and assumes the headship of the entire department of psychology.

PROFESSOR A. PICK, the well known neurologist at Prague, is about to retire from his position as Professor at the University of Prague, and is willing to sell his library. It contains about 3000 volumes and about 7000 brochures, reprints and theses, on neurology, psychiatry and psychology, in English, French and German. Communications should be addressed to Professor Arnold Pick, Jungmannstr., 26, Prague, Czechoslovakia.

THE National Research Council has elected Dr. Raymond Dodge, professor of psychology, Wesleyan University, Chairman of the Division of Anthropology and Psychology for the year 1922-23.